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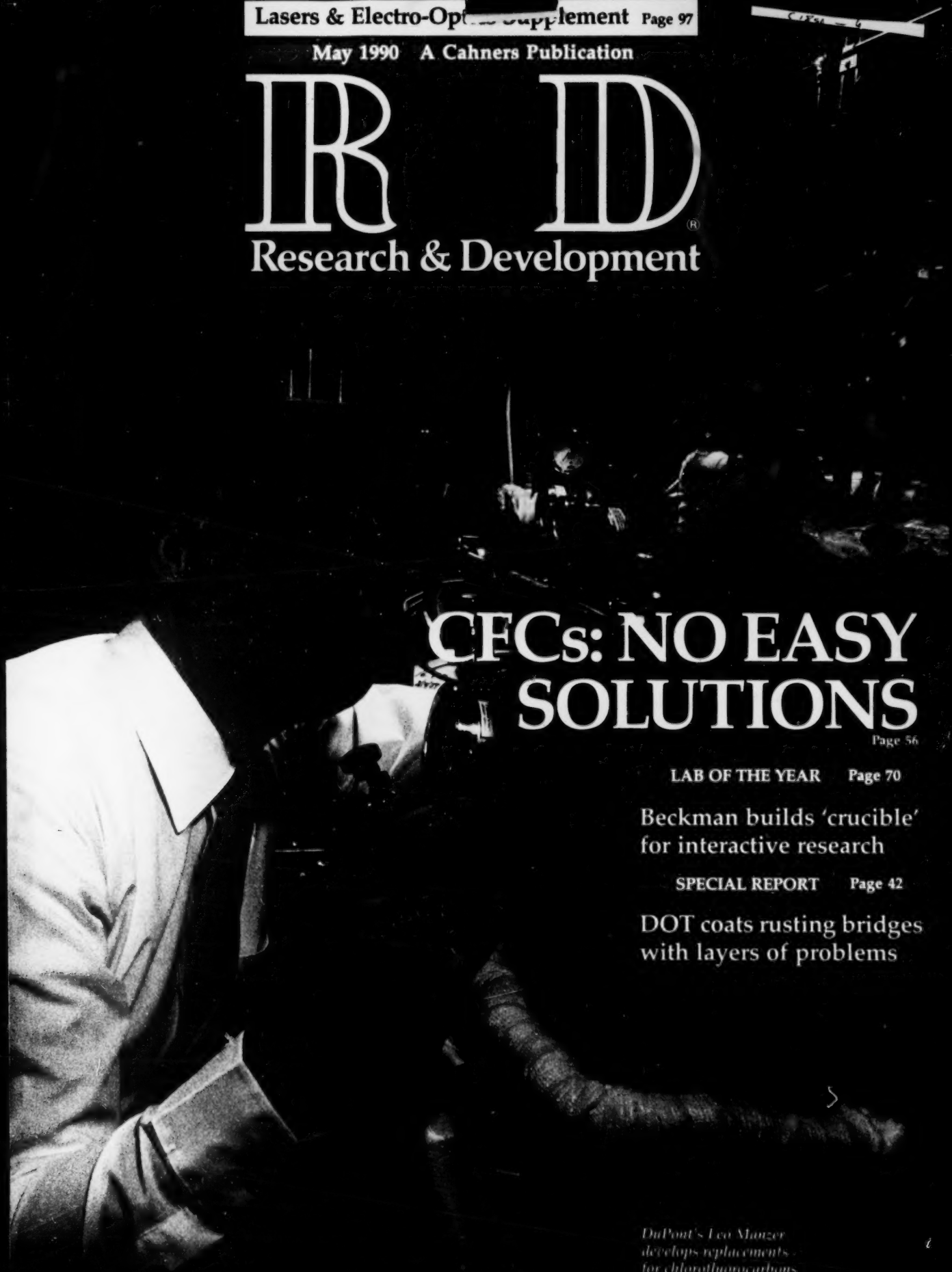

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DOT coats rusting bridges with layers of problems

DuPont's Leo Manzer develops replacements for chlorofluorocarbons

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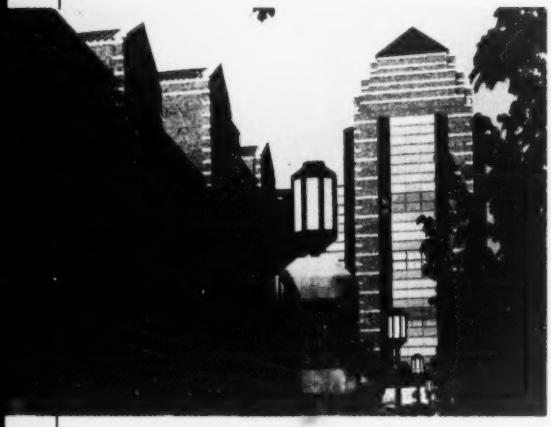

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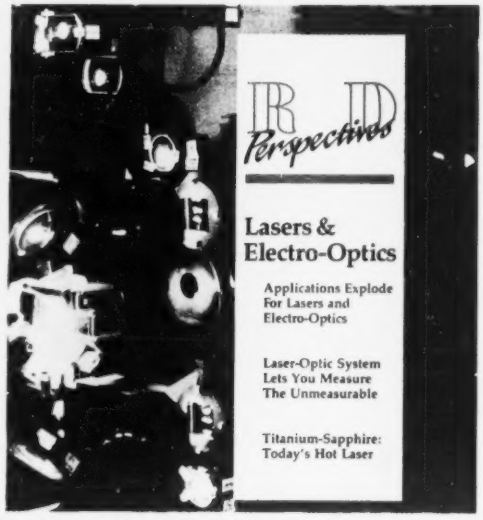
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Leo Manzer, a researcher at DuPont in Wilmington, DE, checks a system that produces experimental quantities of replacements for chlorofluorocarbons. See story on page 56. Photograph by Joe Nettis

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BUSINESS

U.S. research costs twice that of Japan's

IT COSTS substantially more for U.S. firms to finance long-term R&D projects than it does for Japanese companies, says Robert McCauley, a research officer and senior economist for the Federal Reserve Bank of New York.

McCauley calculates that for an R&D project with a 10-year payoff a U.S. company's average cost of capital is about 20% compared to about 9% for a comparable Japanese company.

"The driving factor for the U.S.-Japanese differences is the cost of equity," says McCauley, referring to the sustainable post-tax profit rate.

The other factor in the cost of capital, the cost of debt, actually is not much different in the U.S. and Japan. After adjusting for inflation and allowable tax deductions, both countries have debt costs between 1% and 2%.

The cost of equity for U.S. companies averages from 10% to 12%, while for Japanese firms it averages from 3% to 5%. The continuing emphasis by U.S. companies, and their stockholders, on short-term profits is the driving factor in this relationship.

Most of the stock of large Japanese companies is held by other Japanese companies, often in the same industry group. These companies agree to hold the stock for long periods with few demands for returns, according to a recent U.S. Office of Technology Assessment report, *Making Things Better.*

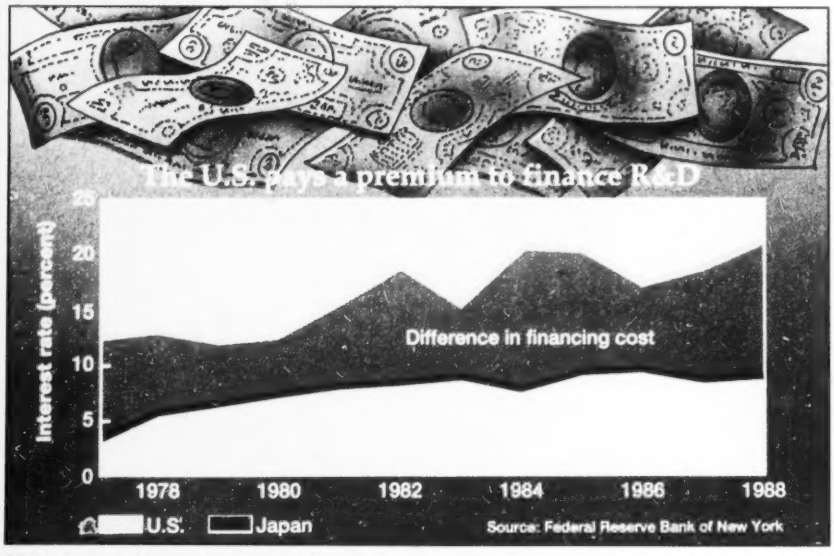
This holds down the cost of capital for those Japanese firms and lowers the long-term financing cost of R&D projects and capital equipment.

The recent large drop in the Tokyo stock market combined with increasing foreign interest rates and lower U.S. interest rates will "narrow the gap slightly, but not much," says McCauley. "A [sustained] 20% drop in the Tokyo stock market would raise Japan's cost of capital less than 1%," he says.

Government R&D tax credits can significantly affect R&D costs of capital. The combined equity and debt costs for German and Japanese firms are about the same, as are those for U.S. and UK firms.

However, because the UK and German firms don't have the 20% to 25% tax credits enjoyed by U.S. and Japanese companies, the costs of capital for a typical R&D project with a 10-year payoff is 4 to 5 percentage points higher for the German and UK firms.

—Tim Studt



***U.S. companies pay** 12 percentage points more than Japanese firms to finance their long-term R&D projects. This reflects the U.S. demand for short-term returns.*

Capillary electrophoresis market to grow tenfold

THE CAPILLARY-electrophoresis instrument market will experience explosive growth over the next five years to $100 million a year, according to a recent study by Strategic Directions Intl., a Los Angeles-based market research firm.

The forecast includes only those instruments used in research and does not include the potential for other undeveloped applications.

Most CE systems now are sold in North America. Japanese and German researchers use gel electrophoresis instruments, which is a potential expansion market for CE systems.

Patents increase as U.S. cuts processing time

THE U.S. Patent and Trade Office issued a record 102,712 patents in FY89, up 22.3% over FY88 figures. PTO also reduced the average time to process a patent application to 18 months in 1989 from 25 months in 1983.

To catch up on the backlog of patent applications, an accelerated processing situation could account for up to 10% of the large atypical increase.

All global regions increased the number of U.S. patents they received. **Pacific Rim** countries received 22,611 patents, up 25.3%, with 20,907 going to Japanese residents, the largest number issued to a foreign country.

West European countries accounted for the second largest number of patents with 22,159, up 16.9%. West German (8,756), UK (3,378), and French (3,310) inventors had the largest share of this region.

East European inventors, while receiving 25.4% more patents in 1989, only accounted for 419 patents.

Third World countries also had a significant increase, up 28.8%, but they received only 684 patents.

U.S. inventors received 54,762 pat-

ents, an increase of 24.2%.

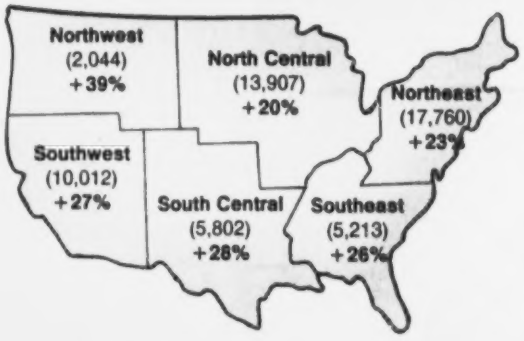
The PTO reported that the U.S. share of patents increased from 52.7% in 1988 to 53.3% in 1989, reversing a steady decline over the past 25 years.

California inventors received the largest number of patents (8,508), nearly twice the amount received by New York residents (4,527).

The demographics of patents within the U.S. correlates with the combined demographics of corporate headquarters locations and population.

A record number of patent applications (163,306) also were filed in FY89, up 10.2%, according to the PTO. □

Patents increase in every region from 1988 to 1989



Source: U.S. Dept. of Commerce

All regions of the U.S. had large increases in the number of patents issued in 1989.

In addition, the share of patents issued to foreign residents was reversed for the first time in more than 10 years.

Composite materials makers value quality more than R&D

COMPOSITES SUPPLIERS still feel that R&D is important, but not as important as it was in 1989 or 1988, according to Owens-Corning's annual survey of industry executives.

In 1988, executives cited R&D as the most important factor in their company's growth. However, in 1989 and again this year, product quality was listed as the most important factor. Although R&D was the second most important factor for the past two years, it continues to lose importance, being cited by only 18% of the respondents compared to 22% in 1989 and 30% in 1988.

The survey also noted that more companies (53% vs. 42% in 1989) are forming R&D partnerships with other companies, but fewer are working with foreign companies (23% vs. 68% in 1989).

"We're working in direct collaboration with domestic thermoplastic suppliers on [fiber-reinforced] product improvements," says Michael Griffith, vice president of R&D for Owens-Corning, Granville, OH. **R&D**

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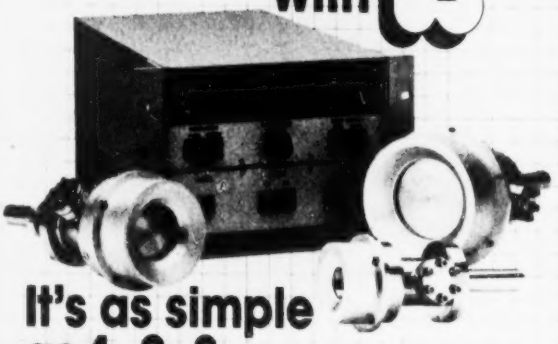

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CFCs

No Easy Solutions

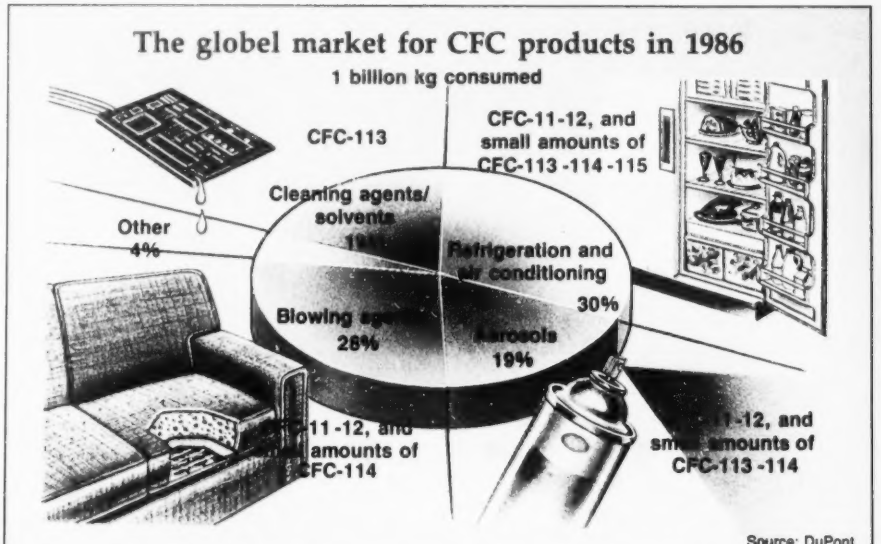
Researchers find no simple victories in their struggle to develop replacements for chlorofluorocarbons.

By Skip Derra, Associate Editor, R&D Magazine

LEO MANZER, a research manager at the central R&D facility of E.I. DuPont de Nemours & Co., marvels at the simplicity and versatility of CFC-113.

"This is a beautiful compound," the 43-year-old chemist says of CFC-113 ($C_2Cl_3CF_3$), which is used widely by industry as a solvent and parts degreaser. "It has great wetting properties—it doesn't bead up like water.

"It can get into all of those tiny nooks and crannies on printed circuit boards and clean off all of the residual flux," he says. "It doesn't harm surfaces. It has been used to clean sensitive gyroscopes and equip-

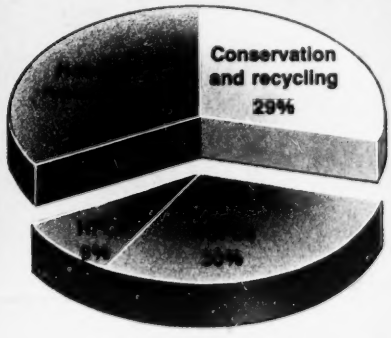

The globel market for CFC products in 1986
1 billion kg consumed
CFC-113
CFC-11-12, and small amounts of CFC-113 -114 -115
Cleaning agents/ solvents
Other 4%
Refrigeration and air conditioning 30%
Blowing agents 28%
Aerosols 19%
11 -12, and amounts of CFC-114
-12, and amounts of CFC-113 -114
Source: DuPont

***Before the Montreal Protocol,** the market for CFCs, especially as a solvent in electronics, was growing as industry found the compounds to be cheap and easy to use.*

Leo Manzer checks instrumentation in his lab at DuPont, where he heads a team of researchers who are developing CFC substitutes.

CFC demand in 2000

1.5 billion-kg market (without regulation)



Source: DuPont

Not-in-kind replacements, stringent recycling programs, and alternate compounds will help to meet CFC demand in the year 2000, when the compounds will be outlawed.

Industry will spend between $5 billion and $7 billion to convert to CFC substitute compounds.

ment on the space shuttle. This is a magical compound.

"But so far, there isn't a single compound that has been found as a replacement for 113," says Manzer, who heads DuPont's efforts into alternate CFC compounds. "That is the molecule everybody is looking for."

Replacing perfect compounds

Manzer and several researchers working under his direction are struggling to come up with replacements for what many people believe are perfect compounds—chlorofluorocarbons. Researchers at DuPont's Wilmington, DE, research facility and around the world feverishly are trying to find the right compound to replace such "magical" chemicals as CFC-113. So far, they have found "suitable" replacements, not magical compounds.

Next month, delegates from 45 countries will meet in London to sign a strengthened version of the 1987 Montreal Protocol that will probably phase out production of five of the most widely used CFC compounds and three Halon compounds by 2000.

The countries are doing this because CFCs destroy Earth's ozone layer, which shields us from the Sun's harmful ultraviolet rays. Continued destruction of the ozone layer eventually will destroy life on Earth, atmospheric scientists say.

But phasing out CFCs will be painful.

CFCs are used by 375,000 businesses to provide $28 billion of goods and services each year in the U.S. alone, according to the Alliance for Responsible CFC Policy, Washington, DC.

CFCs are the bloodline of refrigerators and air conditioners. They are an essential ingredient in manufacturing foam insulation, foam rubber, and foam for packaging. Many industries use CFCs to clean intricate parts and sophisticated computer chips and boards. Hospitals use the compounds as sterilants. Europeans use CFCs as aerosol propellants.

DuPont expects to spend nearly $1 billion during the next 10 years to research, develop, test, and market CFC replacement compounds. Manzer says industry worldwide will spend between $5 billion and $7 billion to convert to alternate compounds.

For Manzer, who received a BS from Univ. of Waterloo (Ontario), and a PhD in organometallic chemistry from Univ. of Western Ontario, London, the challenge is both exhilarating and exhausting.

"It's satisfying that our work will be commercialized in a very short time. What we do will have an impact on everybody in the world," says Manzer, who has worked at DuPont for 16 years. "There are not many times you can say that."

In Manzer's lab, 20 chemists and chemical engineers are working around the clock to come up with new processes to make the eight or so alternate chemical compounds identified as key replacements. Less than three years ago, the researchers were looking at a possible 600 compounds.

"There has been a lot of trial and

For refrigeration, compressed helium might be the answer

FOR YEARS Stephen Malaker, founder of Cryodynamics Inc., Mountainside, NJ, knew he had something special with his cryogenic cooler, but he couldn't talk about it.

Malaker couldn't talk about his modified Stirling engine because it was being used by the military in reconnaissance and night surveillance systems.

"It was so secret we couldn't get any publicity on it," says the 67-year-old physicist.

Now, with the battle being waged on CFCs, Malaker talks freely about his invention, which uses compressed helium as a refrigerant.

While the technology currently is being adapted for refrigeration, "it looks like we have a viable alternative," he says.

Most of the CFC alternatives bring with them tradeoffs in performance and energy efficiency and require modifications to existing refrigerators. It also has been difficult to find a lubricant for HFC-134a, a leading alternate refrigerant.

Malaker's approach to these problems has been to redesign a refrigerator to use compressed helium as the working fluid. Malaker says the modified Stirling engine has a number of advantages.

First, it is a proven technology developed in the 1960s during the Vietnam war and based on a number of patents. In addition to military uses, the system has been used on space shuttle and *Skylab* missions. Cryodynamics currently produces a compressed helium refrigeration system for truck transports.

Stephen Malaker shows the compressed helium refrigerator that he could not talk about for years because it was being used by the military.

Second, the modified Stirling engine is more efficient than other alternate systems, Malaker says. A home refrigerator using his system will need only 5 $in.^3$ of helium compressed to about 200 psi.

"It comes to something like 75¢ of helium per home refrigeration system," Malaker says.

Cryodynamics is working with Admiral Co., Galesburg, IL, to develop a 20-ft^3 home refrigerator that will be cost competitive with what is on the market today. Automakers also are interested in adapting the technology for car air conditioning systems, Malaker says.

The refrigerator's most important attribute is that it will get away from using ozone damaging materials, such as CFCs and their first generation substitutes.

"Helium is totally benign," Malaker says. "It does not react with anything."

***Cheryl Finley, a researcher** at Allied-Signal, checks equipment used to manufacture CFC substitutes, which will help stabilize atmospheric chlorine levels.*

Photo: IBM San Jose/Cindy Charles

***A technician at IBM Corp.** removes storage disks that have been washed with a new water-based process. Electronics companies are finding that simple parts can be cleaned with substitute processes, but intricate circuits will require using HCFC solvents.*

error," the Canadian-born chemist says.

From these compounds (see chart) will come a host of blends optimized to mimic the CFCs they replace. But the scientists admit that these compounds are not a perfect solution to the ozone depletion problem. These are the first wave of alternate compounds that will help wean the world from CFCs.

As experts see it today, replacing CFCs will rely as much on changing business practices as developing new compounds. Satisfying the 2.5 billion lb/yr CFC demand will mandate a stringent CFC conservation and recycling program. It also will require industries wherever possible to use not-in-kind replacements, such as terpene-based cleaners and solvents and hydrocarbon and water blowing agents.

By 2000, nearly 40% of the market is expected to rely on hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs), the replacement compounds that Manzer's group is working on.

Buying time

The alternate compounds will fill the most demanding applications and achieve two goals. They can help to stabilize the chlorine loading in the stratosphere, which is expected to peak at 4 ppb, and they buy time.

These alternate compounds "allow industry time to come up with non-chlorine-based technologies," says Mike Kurylo, who heads NASA's ozone research program while on leave from the National Institute of Standards & Technology.

But HFCs and HCFCs bring with them problems as well as solutions. The chemistry to make the compounds is two to four times more complex than that for CFCs, meaning they will be costly.

"Building a plant to make these compounds is equivalent to building three or four plants to make CFCs," Manzer says.

The complexity of the substitutes has had an effect on the materials used in their manufacture. The substitute compounds are designed to be less stable than CFCs and because of this they also are less robust during the manufacturing process.

This instability of the new compounds means they tend to decom-

"We would love to come in the lab tomorrow and say 'Eureka, we have the magic compound,'" says Manzer.

pose on catalyst surfaces, deactivating the catalyst. Part of the job of Manzer's group is to develop different types of catalysts that can stand up to the new molecules during their manufacture.

Environmental concerns also could spell doom to these compounds at any time.

HFC compounds, where hydrogen is used in place of chlorine, do not deplete the ozone but do contribute to the greenhouse effect. HCFCs, which use hydrogen as a trigger mechanism to make them degrade in the troposphere before they can reach the ozone layer, still deplete the ozone, though at a rate of 2% to 10% that of fully halogenated CFCs.

These attributes make the compounds unacceptable to some people.

"When you look at these chemicals," says Erik Johnson, coordinator of Greenpeace's ozone protection campaign, "you have to look at ozone depletion potential (ODP), at the waste stream involved, the greenhouse gases, and the toxicological problems. You have to go the whole nine yards."

Promising chemicals and technologies are on the horizon, such as the use of fluoroethers and technologies like the compressed helium refrigerator. But these technologies either require changing infrastructures or cannot be developed in time to meet the Montreal Protocol deadline.

"We would love to come into the lab tomorrow and say 'Eureka we have the magic compound,'" says Manzer. "But nobody has found it yet."

The substitute compounds are not the perfect replacements, says Bernie Sukornick, 62, director of R&D for Allied-Signal's Fluorocarbon Div., Buffalo, NY, the second largest U.S. producer of CFCs. "But they are a damn good direction in which to go.

"You don't invent molecules overnight," Sukornick adds. "Especially ones that have zero ODP and very little greenhouse effect."

Back to the future

All of the alternate compounds being worked on today were first discovered in the 1920s and 1930s. It was during this period when a team of researchers headed by Thomas Midgley at General Motors discovered CFCs.

These alternates then were refined during the 1970s, when the first scientific data linking CFCs and ozone depletion were published. Making the substitute compounds, not discovering them, is the challenge today.

"It seems like we are going to make

Half the battle is getting out of the CFC bias

RESEARCHERS trying to find alternates to CFCs face a major challenge just in eliminating the notion that CFCs are the perfect compound.

For product engineer Bill Kopko, York Intl. Corp., York, PA, getting out of this bias meant going to the company library and burying himself in vintage technical reports.

"I wanted to see what people were looking at [as replacement refrigerant compounds] in the 1920s and 1930s—pre CFCs," Kopko says. "The researchers then didn't have any preconceived notions, they were trying anything that could be used."

What Kopko found was a 1937 patent for halogenated methyl ethers issued to Harold Booth and assigned to Westinghouse, along with data on dimethyl ether and cyclopropane compounds. Some of these compounds have thermodynamic properties similar to CFCs and have a relatively simple structure, meaning they might have good cycle efficiency.

"There is enough information to show that some of these compounds are reasonably stable and have low toxicity," Kopko says.

For example, a difluoromethyl fluoromethyl ether compound has a boiling point—a key property for refrigeration—that comes close to CFC-11. A bis-difluoromethyl ether has essentially the same boiling point as CFC-114, Kopko says.

The U.S. Navy is interested in a bis-difluoromethyl ether compound as a substitute to CFC-114 in its refrigeration systems and has contracted with the National Institute of Standards & Technology to test the compound.

Although promising, fluoroethers are a long way from commercialization. But Leo Manzer, who heads DuPont's research into CFC substitutes says all technical problems aside, the compounds could be second generation replacements if their costs aren't prohibitive.

Whether fluoroethers are the magical compound chemists are looking for or not, Kopko's work illustrates that finding a replacement for CFCs might be a matter of perspective.

***Bill Kopko** at York International Corp. studies vintage technical reports at the company library to see what chemists in the 1920s were working on before CFCs were developed.*

'It seems like we are going to make great advances and end up back where we were in 1930,' says NIST's Didion.

great advances and end up back where we were in 1930 [with flammable refrigerants]," says David Didion, a mechanical engineer at NIST, who tests alternate compounds for refrigeration and air conditioning systems.

Of all CFC uses, refrigeration and air conditioning will present the most problems because existing systems are engineered around CFC-12. This means the substitutes must match the operating properties of CFCs so they can be used in the $135 billion of existing equipment that employ CFCs.

The mess with oils

Developing oils and lubricants that will allow the new compounds to be used in the pressure cycles of a refrigerator or air conditioner is critical. With HFC-134a, a key replacement for CFC-12, one problem is developing a miscible oil.

DuPont, Allied-Signal, ICI, and Atochem say they have proprietary lubricants that look promising for substitute refrigeration compounds. But some researchers are unconvinced.

"The engineering problems associated with HFC-134a and HCFC-123 are horrendous," says NIST's Didion. "Companies are spending tons of money developing these compounds, and it is not clear at all that 134a has an oil yet," he says.

Modifications to existing equipment also will be needed to use the alternate compounds in these systems. Researchers already have encountered

A biomedical scientist at General Motors exposes cell cultures to HFC-134a, a key substitute for CFC-12 used in car air conditioners, to determine the compound's toxicity. Design changes to automobiles will be required before HFC-134a can be used.

What's in and what's out in CFCs

	Compound	Lifetime (years)	Ozone depletion potential (avg)	Global warming potential (avg)	Primary uses
WHAT'S IN	HCFC-22	15	0.05	0.34	Air conditioning, refrigeration, foam packaging
	HCFC-123	2	0.02	0.02	Refrigeration, insulating foams, solvents
	HCFC-124	7	0.02	0.1	Air conditioning, insulating foams
	HCFC-141b	8	0.1	0.09	Insulating foams, solvents
	HCFC-142b	19	0.06	0.36	Insulating foams, solvents
	HFC-125	28	0	0.58	Refrigeration
	HFC-134a	16	0	0.26	Refrigeration, air conditioning
	HFC-152a	2	0	0.03	Insulating foams, aerosols
WHAT'S OUT	CFC-11	60	1	1	Insulating foams, refrigeration, air conditioning
	CFC-12	120	1	3	Refrigeration, air conditioning, insulating foams
	CFC-113	90	0.8	1.4	Solvents
	CFC-114	200	0.7	3.9	Foam packaging, aerosols
	CFC-115	400	0.4	7.5	Refrigeration

Source: World Meteorological Organization 1990 report

***While HFC and HCFC** compounds are not entirely benign, they cause considerably less damage to the ozone and contribute less to the greenhouse effect than the fully halogenated compounds they replace because of a shorter atmospheric lifetime.*

The best substitutes for foam blowers are HCFCs, but legislative action could eliminate their use.

problems with swelling gaskets and seals, and with reactions of the new compounds to the epoxies that coat the motors.

"Little by little, they are finding that they can use this epoxy or that epoxy, this gasket or that gasket," Didion says. "Little by little the problems are being solved."

Matching the properties of CFCs is especially crucial for the automotive users because not a lot of leeway exists to modify air conditioning systems to run on the alternates. Also, by 2000, nearly 75 million cars with air conditioners designed around CFC-12 are expected to be on the road.

Blends of two or three alternates are being developed to come as close as possible to matching the thermodynamic properties of CFC-12. DuPont has formulated a blend of HCFC-22, HFC-152b, and HCFC-124 as a replacement for CFC-12 in car air conditioners. Allied-Signal has a similar blend of alternate compounds.

Trouble with blends

"None of these compounds are drop ins," says Jerry Stofflet, assistant director for automotive emission control of the environmental activities at General Motors, Warren, MI.

"All of them require changes to the automotive systems," Stofflet says. "The big problem with blends is that you cannot recycle them on the spot. You will have to put them in a tank and ship them across state lines, and that creates more problems."

Stofflet says 28 design changes will be needed for GM cars and trucks to use the new compounds. He says the changes will be unnoticeable to consumers, although costs are expected to rise.

Electronics companies have ambitious programs for phasing out CFCs. Motorola Inc., Schaumburg, IL, plans to phase out all CFC emissions by the end of 1992. IBM Corp., Armonk, NY, has a complete phaseout deadline by December 1993, and AT&T Microelectronics, Berkeley Heights, NJ, by 1994.

Companies are modifying their production processes to eliminate using CFCs as solvents and cleaners. Some of the companies are using aqueous cleaners, deionized water cleaning systems, and low- or no-flux soldering processes.

But the worry in electronics is the

Europe and Japan act swiftly to phase out CFCs

EUROPEAN and Japanese CFC makers and users have acted swiftly in response to the Montreal Protocol restricting CFC use.

The European Community, which produces 38% of the world's annual CFC supply, has a lot at stake in the conversion to substitutes. Here is what some European CFC producers are doing.

♦ ICI Chemicals & Polymers Ltd., England, is building HFC-134a production plants in Saint Gabriel, LA, and in Runcorn, Cheshire, England. ICI has invested $170 million in the two plants, which will produce a substitute refrigerant for CFC-12.

♦ Montefluos SpA, Italy's top CFC producer, is working on HFC-123 for foam blowing and HFC-134a for refrigeration. The company has built a pilot plant for both compounds and has applied for patents on its manufacturing processes.

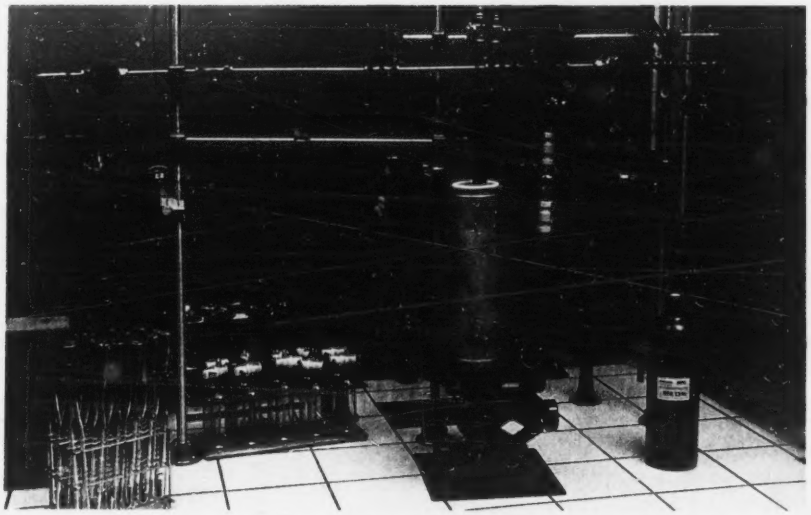
♦ Bayer AG, West Germany, has been working with refrigeration equipment manufacturers and with foam blowers to reduce the amount of CFCs by 50% in each application. Bayer also is developing chlorofluoroalkanes to be used with HCFC-22 to make a less stable product that decomposes before reaching the stratosphere.

♦ Atochem SA, a French chemical manufacturer, is testing an HFC-134a formulation for refrigeration. Atochem already has two alternate compounds on the market—HCFC-141b (a blowing agent) and HCFC-142b (a refrigerant).

♦ In Japan, the Ministry of International Trade & Industry has teamed up with Japanese chemical manufacturers in a five-year $40 million project to identify and produce alternates to CFCs. Nearly half of the CFCs consumed by the Japanese is for solvent uses in electronics manufacture.

In addition to developing new solvents, the Japanese are looking into recycling systems and alternate cleaning technologies.

One new method, developed for the cleaning of precision machinery, uses 10-μm ice crystals of pure water. Operating at temperatures of −50 C, the method first freezes impurities that are on the surface of the part and then injects the ice crystals to blast them away.



Chemicals cook in a lab at Atochem SA, Paris, during tests on CFC substitute compounds. Companies in Europe and Japan have been developing substitute compounds and alternate processes to meet the needs of the changing CFC market.

It will take 95% global compliance of the CFC ban to stabilize the chlorine levels in the stratosphere.

A Union Carbide researcher tests the resiliency of a non-CFC foam by measuring the bounce of a steel ball off of the foam.

How will the CFC phaseout affect your business?

HERE IS A list of information sources for finding out how eliminating CFCs will affect your business.

Associations

The Alliance for Responsible CFC Policy, 2011 Eye St. NW, Suite 500, Washington, DC 20006 (contact: David Stirpe).

American Electronics Assn., 1225 Eye St. NW, Suite 950, Washington, DC 20005 (John Hatch).

American Society of Heating, Refrigerating & Air Conditioning Engineers Inc., 1791 Tullie Circle NE, Atlanta, GA 30329 (Tony Giometti).

Greenpeace USA, 1436 U St. NW, Washington, DC 20009 (Peter Dykstra).

Government Agencies

Environmental Protection Agency, 401 M St. SW, Washington, DC 20460 (Stephen Anderson).

National Institute of Standards & Technology, Gaithersburg, MD 20899 (David Didion).

Manufacturers

Allied-Signal Inc., Box 1087R, Morristown, NJ 07962 (William Corcoran).

Atochem NA Inc. (formerly Pennwalt Corp.), 3 Parkway, Philadelphia, PA 19102 (Charlie Kitchen).

E.I. DuPont de Nemours & Co., 1007 Market St., Wilmington, DE 19898 (Cathy Andriadis).

Users

Cryodynamics Inc., 1101 Bristol Rd., Mountainside, NJ 07092 (Stephen Malaker).

General Motors Technical Center, 30200 Mound Rd., Warren, MI 48090-9010 (Toni Simonetti).

IBM Corp., Armonk, NY 10504 (Mack Jeffery).

York Intl. Corp., Box 1592, York, PA 17405-1592 (Bill Kopko).

cleaning of high-end products, where intricate circuit patterns and chip connections must be almost completely free of flux and residue.

"We have used a lot of [alternate] cleaning products on boards in the past, but they have been relatively simple products," says Tim Mann, who oversees IBM's program to phase out CFCs. "The more complex the boards, the more you will have to rely on using HCFC solvents."

End users are concerned too.

"The whole automotive industry is worried about CFC-113," says GM's Stofflet, who also is chairman of the Motor Vehicle Manufacturers Assn. panel on CFCs. "That compound is used to clean the fuel emission control electronic chip. Any residue that is left on it will degrade the reliability of our product."

Foam blowers, who have built their businesses on reliable and cheap CFC blowing agents, also will face a tough time converting to alternate methods. The companies are finding that several methods can be used, but they lower product quality.

Foam blowers have used CFC-11 to expand rigid polyurethane and polyisocyanurate foams and CFC-12 to expand extruded polystyrene board foam. Many companies have developed combination processes that let them reduce CFC use 30% to 50%. Eventually, compounds such as HCFCs-123 and -141b will replace CFC-11 and HCFCs-142b and -124 will replace CFC-12.

Foam blowers are working on water blowing and carbon dioxide blowing processes. Hydrofluoroalkane also is being used as a blowing agent for furniture padding, but the compound is 75 times more expensive than CFC blowing agents.

HCFC restrictions

The best alternate foam blowing agents are the HCFCs. But legislative action, such as Sen. John Chaffee's (R-RI) bill to phase out these compounds, could put severe restrictions on these agents or even eliminate their use.

Everything must go according to plan in order to meet the deadlines of the Montreal Protocol. Many chemical companies are moving ahead with plans to produce HFCs and HCFCs before their toxicity tests are complete or before laws governing their use are finalized. The chemical companies are gambling hundreds of millions of dollars in building new facilities.

Global compliance is the key to making the protocol work and to reducing damage to the ozone layer. It will take at least a 95% worldwide compliance just to stabilize the chlorine loading in the stratosphere, says NASA's Kurylo.

"We know if you stop [using CFCs] the atmosphere will cleanse itself," he says.

But that means India, China, Israel, and other countries that have not signed the protocol must participate to make it work.

"Everything is in place to [phase out CFCs]," says Manzer. "But whether everyone in the world will agree to a total phaseout of CFCs, your guess is as good as mine." **R&D**

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High **377** Medium **379** Low **381**

What's a PhD Worth? Try $2 Million

The more education you get, the better your chances for a higher salary, our survey reveals.

*By **Robert R. Jones**, Executive Editor,* R&D Magazine

THE FINANCIAL ADVANTAGE for workers in R&D of having a PhD degree instead of just a bachelor's degree now exceeds $2 million over a 35-year career, according to the 3,800 respondents to our recent industry survey.

When all of the data are considered, the typical worker in research and development in 1990 is a 44-year-old male chemist with an MS degree, working in industry, with 18.7 years' experience and 10.3 years with his present employer. He received a 4.8% salary increase last year and now is earning just under $50,000 a year.

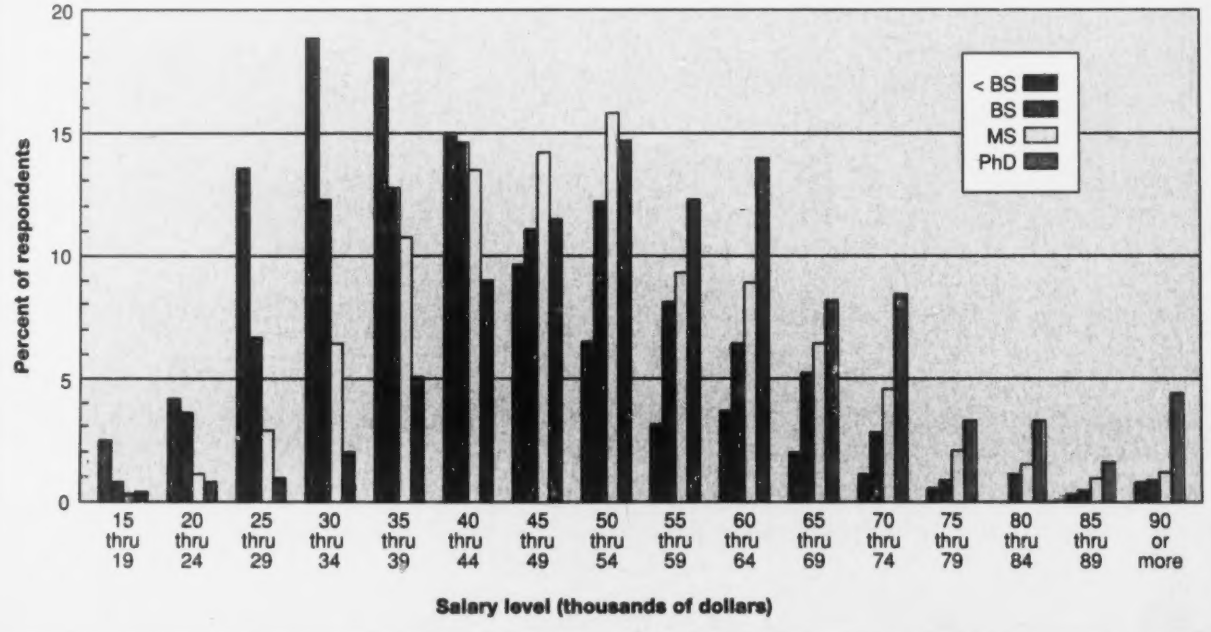
The PhD vs. BS premium in R&D has increased steadily in real value throughout the past decade. In 1980, the premium was $820,472. With an increment added to that figure every year, the premium now is almost 2.5 times that amount.

Added costs included

Today's PhD/BS premium of $2,006,552 represents an increase from 1980's figure at a rate of more than 9.3% compounded annually. That puts it well ahead of the rate of inflation in the U.S.

This premium is calculated from a formula that allows for the added cost

1990 salary by education level for all R&D workers



Pay for education is obvious as R&D workers with no degree dominate lower salary ranges, MSs the middle, and PhDs the top.

of the PhD education, for the earning years that are available to the BS individual while the PhD is being earned, and an interest rate of 8%.

While 35 years sounds like a long career, that figure is reasonable for this industry, based on respondents' reports of their years of experience. Nearly 11% report having 35 or more years' experience, and almost one in 10 of the responding PhDs is more than 60 years old, old enough to have had such a career.

Such a premium for higher education provides a strong incentive to young scientists and engineers to work for advanced degrees.

For example, spread evenly over a PhD's career, that premium amounts to an annual benefit of $57,330 over 35 years.

That premium also can be seen as returning more than $500,000 for each year spent getting a PhD, assuming a four-year doctoral program.

The biggest opportunity

The principal reason for this year's increase in the size of the PhD/BS premium is that, while the median salary for PhDs in research and development went up by 5.1% in 1990 (vs. 7.8% in 1989), the median for R&D workers with a BS degree went up only 4.2% (vs. 9.9% in 1989).

The individual who goes from high school to PhD nabs the biggest premium opportunity. The difference in median annual incomes for R&D workers with PhD degrees vs. those with no degree rose to $19,298 this year from $18,704 last year. Thus, the financial value of having a PhD degree over having no college degree at all now stands at $3.1 million over a 35-year career.

For a person who chooses to go on for a PhD after getting an MS, the 35-year return is more than $1.1 million.

There is an equal $1.1 million-plus career premium for getting a BS instead of not getting a degree at all. Respondents report that the move up from BS to MS is worth nearly $900,000 over a 35-year career. Thus, getting an MS in place of no college degree provides another opportunity for you to earn a career premium of more than $2 million.

Looking at the reward for advanced degrees in another way: Of this year's respondents who are earning $75,000 a year or more, 53.6% have earned a PhD, 24.7% have an MS, 14.5% hold a BS, and 7.2% have no college degree at all.

Among those 3,800 persons who work in R&D and responded to this survey, 9.4% are female, the same percentage of female respondents as last year.

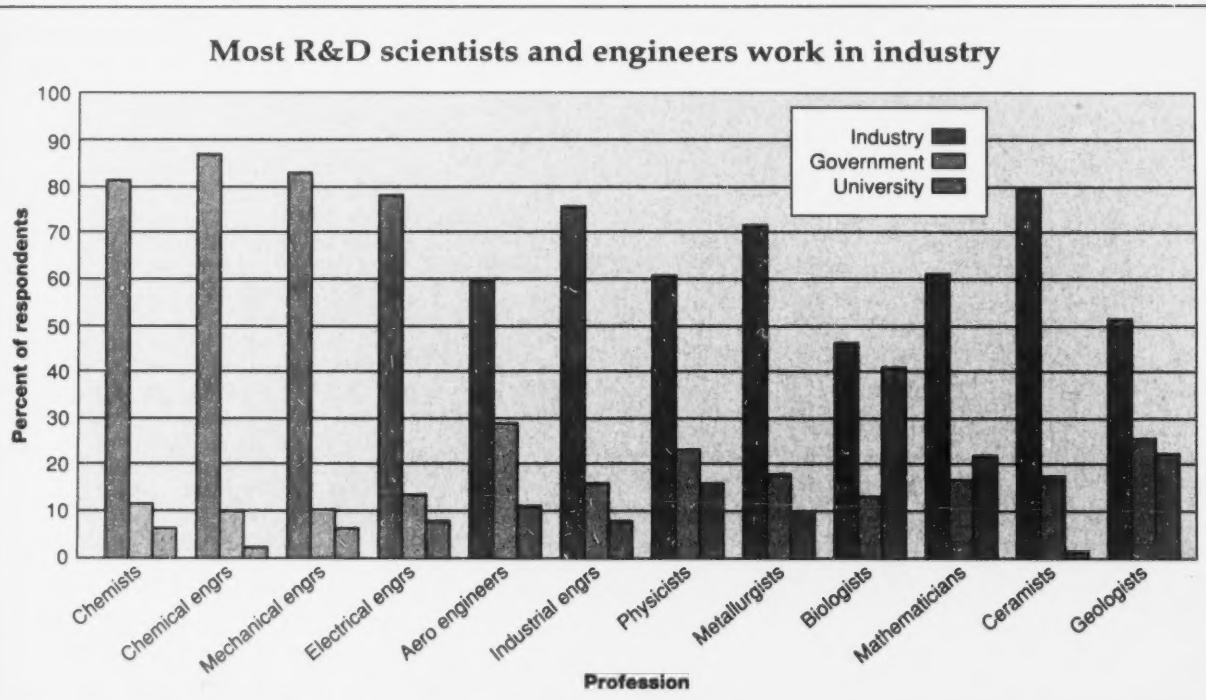
Twice as many females

The percentage of women in R&D has almost doubled over the past decade, from 4.9% in 1980 to 6.3% in 1983, to 7.2% in 1986.

However, much of the foregoing comment about salary premiums does not apply to women. Fewer women than men have earned PhD degrees and even fewer have attained 35-year careers.

Among this year's respondents, the 9.4% who are female hold only 7.7% of the PhDs; moreover, 11.4% of the men in R&D have achieved a 35-year career, while only 3.6% of the women have done so—two major reasons why men are the top money-earners in this industry.

Nonetheless, after all of the cultural factors have been allowed for, a salary difference still exists. Plainly put, there still is sexual discrimination in



R&D chem engineers and ceramists are scarce on college scene, biologists numerous; government likes aero engineers and geologists.

The financial value for an R&D worker with a PhD compared to no degree now stands at $3.1 million.

research and development.

On the positive side, however, the situation is shifting toward equality. In 1980, 9.0% of the female respondents were being paid in the upper half of the salary range. Today, 13.1% of the women are earning salaries in the upper half.

Even within the past year, the percentage of women respondents in the lower income ranges has dropped sharply. In 1989, 48.1% of the women respondents reported incomes in the bottom quarter of the salary chart.

This year, the percentage of women in that salary range is down dramatically, to 33.7%. (The corresponding figures for men were 17.6% in 1989 and 14.2% in 1990, a much less dramatic change.)

Workers in R&D with a PhD can expect to earn $12,000 more this year than those who have only a BS.

R&D salaries compared by academic degrees

Degree	Median salary 1990	Median salary 1989	Percent change	Annual difference* 1990	Annual difference* 1989	Difference change (percent)
Doctorate	$57,138	$54,351	5.1	$7,036	$6,436	+9.3
Master	50,102	47,915	4.6	5,358	4,982	+7.5
Bachelor	44,744	42,933	4.2	6,904	7,286	−5.3
<Bachelor	37,840	35,647	6.1	n/a	n/a	n/a

* Difference above next lower degree

Median salaries all R&D by workplace

	1990	1989	1980
Industry	$49,978	$48,307	$28,354
Government	48,793	45,482	29,733
University	47,500	43,181	25,685

Industry pays the top salaries in R&D today, but was No. 2 prior to 1984.

Salary increases granted in 1989 determine 1990 pay. Women outdid men in getting above-inflation raises.

Percent of R&D workers receiving salary increases by range and sex

Amount of increase	Granted in 1989 Male	Granted in 1989 Female	Granted in 1988 Male	Granted in 1988 Female
None	9.3	7.6	10.0	3.1
Less than 2%	2.6	1.4	5.3	5.6
2 through 5%	55.7	48.5	54.9	50.6
6 through 9%	24.2	30.2	21.4	31.9
10 through 13%	5.4	10.1	5.7	4.5
14% or more	3.3	2.0	2.6	4.3

Median salary by sex and workplace

	1990	1989	% change
Men in industry	$51,015	$49,434	+ 3.2
Men in government	50,061	45,802	+ 9.3
Men in universities	49,166	44,317	+ 0.9
Women in industry	40,705	36,561	+11.3
Women in government	38,654	41,249	− 6.3
Women in universities	34,167	27,499	+24.2

Women working in industrial R&D made the most salary gains last year, but still lag men in all categories. See text for comments on last two categories.

In salary increases last year, women outscored men four to three in the percentage getting increases that were larger than inflation.

The 9.4% of this year's respondents who are women captured 11.4% of the salary increases in the 6%-to-9% range and 16.1% of the increases in the 10%-to-13% range. Although they dropped to 5.8% of the increases of 14% or more, they held onto the 4:3 lead in above-inflation salary boosts.

As we reported in March, the median income for all R&D workers in 1990 is $49,632. When the median is calculated on the basis of sex and workplace (industry, government, or university), it becomes even more obvious that men earn more than women and industry pays better than government or university employers.

As it has for a number of years, the highest median for women's income, the category of women in industry, remains below the lowest-paid group of men, that of men in universities (see accompanying table).

Women making gains

However, women are making gains on men, as the 11.3% increase for women who work in industry would indicate.

There is one change of a different nature: Last year's survey stated that women in government had received salary increases that raised their median income a surprising 23.1%. This put them ahead of women in industry, but still left them lower than the lowest male median.

This large increase smacked more of sampling error than of government beneficence.

As expected, data from this year's survey confirm the suspicion that the 1989 data were flawed. The current median for women in government is down from last year's median. Nevertheless, it still represents a compounded two-year gain of 7.42%—a respectable increase and much more believable.

By the same token, the 24.2% increase that was recorded this year for women in universities calls attention to itself. While it is not large enough to change the rankings, it is an unusually high annual increment and should be looked at skeptically.

For many years, government was obviously the best place for R&D

Aeronautical engineers in R&D dominate upper age ranks, few replacements are coming on at lower end.

workers in terms of salaries. Then, beginning in 1984 with Reagan administration efforts to shift expenditures from government to industry, that changed. In recent years, R&D workers in industry have been the clear winners in the payroll sweepstakes (see accompanying table).

The division of disciplines by workplace categories is shown in the accompanying chart, which reveals that the highest percentage of any R&D discipline to work in government is aeronautical engineers at 29.0%. Only 10.1% of the chemical engineers work for government.

University R&D employs only 1.6% of the ceramists and 2.6% of the chemical engineers. Predictably, industry employs the largest portion of the chemical engineers, as it does in most disciplines.

The lowest percentage of any R&D discipline employed by industry is biologists; 40.8% of R&D biologists are employed by universities. Biologists also rank at the bottom in median salary. And the discipline with the highest percentage of women is biology, at 17.5%.

Small wonder that women biologists working in universities are at the opposite end of the income rankings from male aeronautical engineers in industry.

Where are the replacements?

Data from this survey suggest that there is cause to ask where the next generation of aero engineers may be. While 37.7% of all workers in the R&D industry are 40 years of age or younger, only 25.8% of aeronautical engineers are that young.

At the upper end of the age scale, aero engineers report that 12.9% are older than 65 years of age. This is the only R&D discipline in which more than 4% of respondents are that old.

Next in order of age are physicists, much closer to the industry average, with 33.0% being younger than 41 (mathematicians have 33.4% and industrial engineers 35.1% that young).

The age of physicists in R&D is bunched around the median age for all R&D. Although they are short of younger workers, only 1.9% of physicists are in the older-than-65 category.

In the overall R&D industry, only 3.0% of workers are older than 65. Ceramists and metallurgists are tied for having the lowest percentage of workers older than 65 at 1.6%. R&D

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High **389** Medium **391** Low **393**

1990 profile of the research and development industry

1. What is your annual salary?

$15,000 through $19,999	0.7%
20,000 through 24,999	2.1
25,000 through 29,999	4.6
30,000 through 34,999	8.2
35,000 through 39,999	10.4
40,000 through 44,999	12.6
45,000 through 49,999	11.9
50,000 through 54,999	13.3
55,000 through 59,999	9.3
60,000 through 64,999	9.2
65,000 through 69,999	6.1
70,000 through 74,999	4.9
75,000 through 79,999	1.9
80,000 through 84,999	1.8
85,000 through 89,999	0.9
More than 90,000	2.1

2. Your raise during the past year was

None	9.2%
Less than 2%	2.1
2 through 5%	54.9
6 through 9%	24.7
10 through 13%	5.9
14% or more	3.2

3. How long have you worked for your present employer?

Less than 1 year	4.2%
1 through 3 years	15.5
4 through 6 years	16.4
7 through 9 years	12.9
10 through 12 years	9.4
13 through 15 years	7.5
16 through 18 years	6.3
19 through 21 years	7.1
22 through 24 years	6.3
25 through 27 years	4.8
28 through 30 years	3.6
31 through 33 years	3.2
34 through 36 years	1.3
More than 36 years	1.5

4. What is your age?

Under 26 years	1.9%
26 through 30 years	8.0
31 through 35 years	14.3
36 through 40 years	13.5
41 through 45 years	14.1
46 through 50 years	15.2
51 through 55 years	12.9
56 through 60 years	11.3
61 through 65 years	5.8
Older than 65 years	3.0

5. How many years of experience do you have?

Less than one year	0.7%
1 through 5 years	9.1
6 through 10 years	14.7
11 through 15 years	15.5
16 through 20 years	13.7
21 through 25 years	14.0
26 through 30 years	12.8
31 through 35 years	11.0
36 through 40 years	6.0
More than 40 years	2.5

6. What is the highest degree you hold?

Less than bachelor	9.4%
Bachelor	34.0
Master	24.9
Doctorate	31.7

7. What is your profession?

Chemist	33.9%
Chemical engineer	7.1
Mechanical engineer	13.2
Electrical engineer	10.2
Aeronautical engineer	1.6
Industrial engineer	1.0
Physicist	8.1
Metallurgist	5.1
Biologist	5.4
Mathematician	0.5
Ceramist	1.7
Geologist	0.8
Other	11.4

8. Do you work in

Industry	75.4%
Government	13.9
University	10.7

9. Are you

Male	90.6%
Female	9.4

Applications Explode For Lasers and Electro-Optics

R&D Perspectives

More power, faster pulses, and new materials are opening doors in lithography, diagnostics, and spectroscopy.

By *Tim Studt, Associate Editor,* R&D Magazine

THIS MONTH marks the 30th anniversary of the first laser. On May 15, 1960, Theodore Maiman, a researcher at Hughes Aircraft Co., used a solid ruby crystal to produce the first coherent laser light.

Today, researchers are working without letup to develop new laser systems and expand their applications. They are developing lasers to measure the adhesion of thermal tile to space shuttles, make 3-D models from CAD designs in a matter of minutes, and sculpt human corneas eliminating the need for glasses or contact lenses.

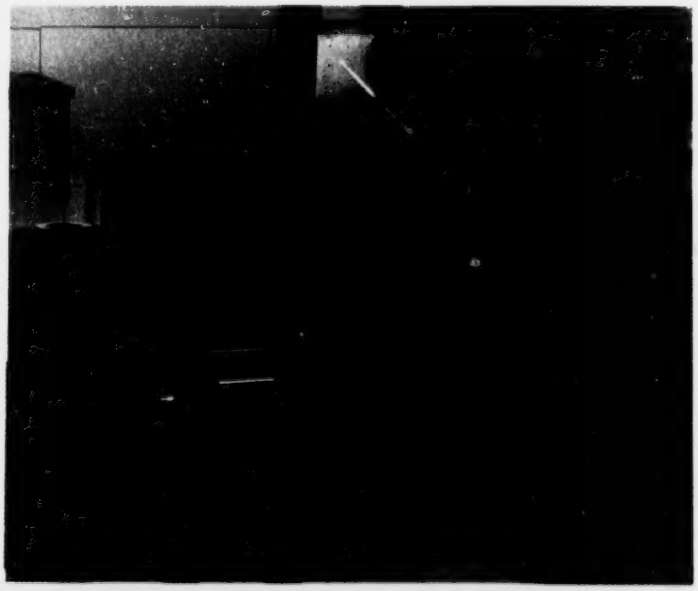
Not even counting the laser R&D being done in fusion and the Strategic Defense Initiative programs, most national laboratories and universities have several ongoing research programs that involve lasers. Most of this work is directed at industrial, medical, and analytical applications.

Using big lasers

Bigger and faster. That's what industrial laser research is emphasizing.

Most heavy industrial laser applications still rely on CO_2 lasers for metal cutting, welding, and ablation.

Conversely, most CO_2 lasers are used for industrial applications. More than 75% of the 2,100 CO_2 lasers sold in 1989 were rated at more than 500 W and were designed for materials-processing says Dennis Fortino, president of the Rofin-Sinar Div. of Siemens Components Inc., Santa Clara, CA.



A Nd:YAG laser at Idaho National Engineering Lab is focused on space shuttle thermal tiles to simulate re-entry conditions. A HeNe laser measures the resultant vibrations.

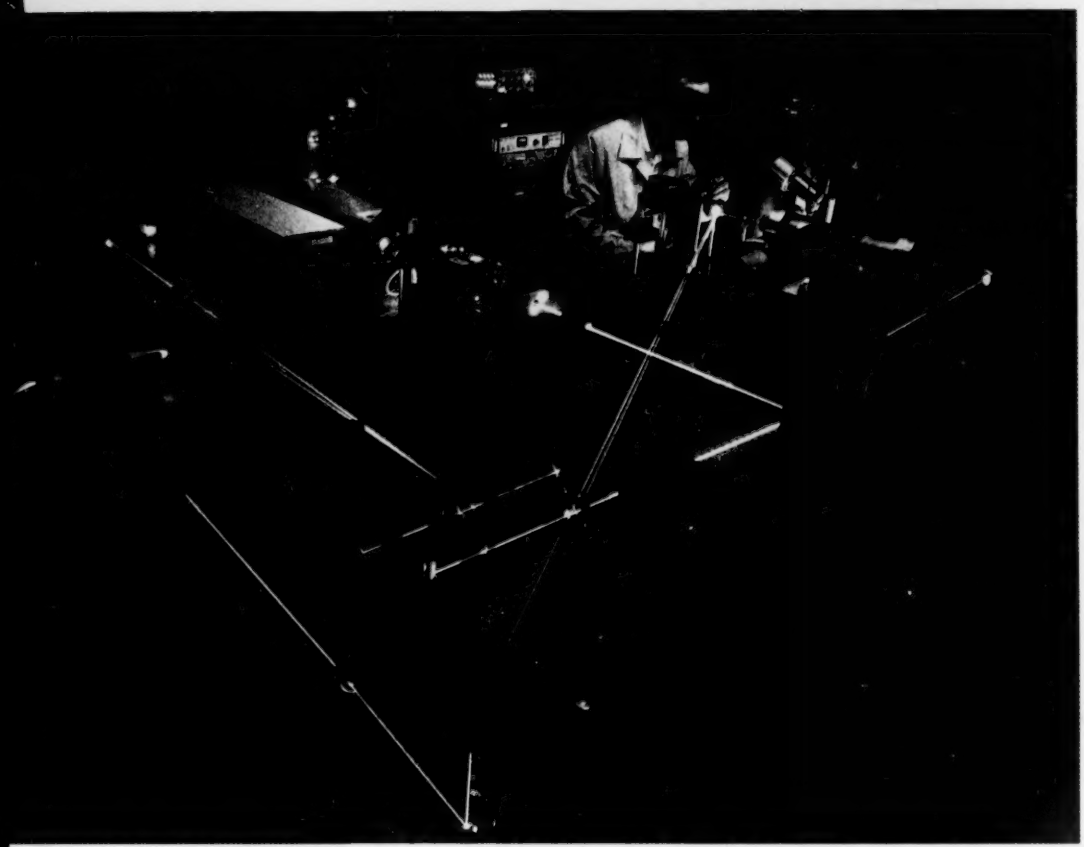
CO_2 laser research has concentrated on increasing power levels, improving power supply efficiencies, and increasing pulsing capabilities.

Power supply research has reduced the footprint of CO_2 systems by half and costs by a third during the past five years. Additional advancements are being realized as solid-state switched-mode and RF sources replace traditional power supplies.

Using microwaves to excite lasers has been discussed for some time, but microwaves do not readily penetrate the discharge plasma generated in a laser. Recently, researchers at Mitsubishi Central Research Labs, Hyogo, Japan, developed a CO_2 laser with a discharge chamber that allows microwave excitation. These lasers are more controllable than traditionally excited CO_2 lasers and can be used to process ceramics and other dielectric materials with less thermal damage.

Additional cavity improvements are being developed. "Current systems are only at 50% of the thermodynamic design limits. We foresee at least two more generations of CO_2 lasers," says Fortino.

For heavy industrial use,



A researcher at Battelle's Pacific Northwest Lab combines two dye lasers with a CO_2 laser to create a high sensitivity mass spectrometer that can measure radon exposure in humans.

even higher power levels than the 10- to 25-kW systems now available are desired. One application for high-powered systems is spot welding of automotive body sections.

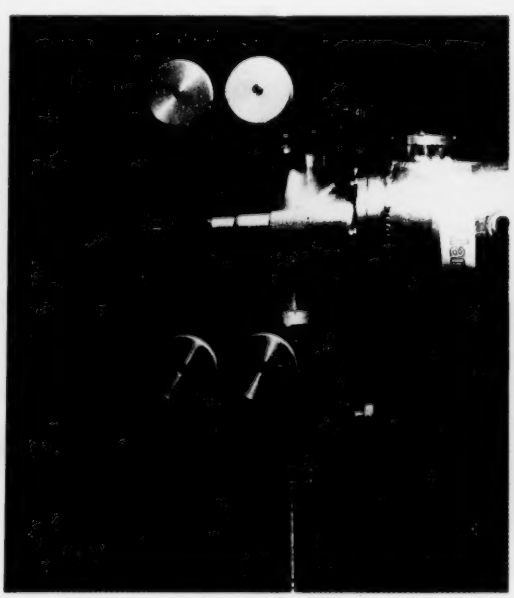
A typical car has about 9,000 spot welds, with 50% of them redundant. Using an automated laser process could eliminate 80 lb of spot-weld flange material per car.

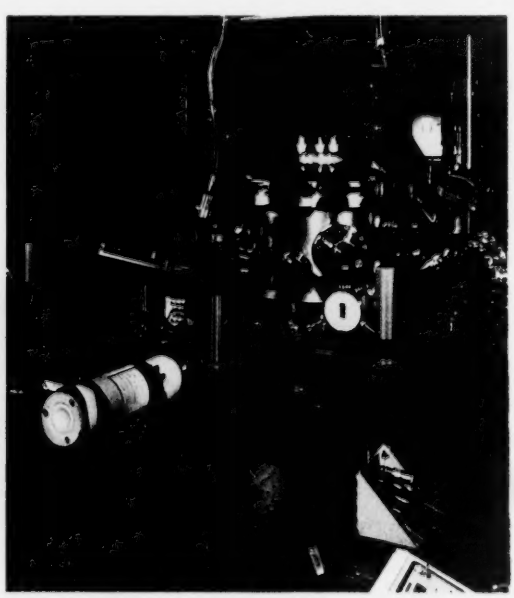
Most domestic automotive firms have laser technology groups working in this area. A few General Motors production cars already have internal body subassemblies welded with CO_2 lasers.

Because of their inherent reliability and low cost, most of the industrial laser research is devoted to refining CO_2 lasers.

Excimer and solid-state lasers also are being increasingly used in specific industrial application areas, such as low-power welding, processing of organic materials, and semiconductor lithography.

Solid-state Nd:YAG lasers are inherently easier to operate than CO_2 lasers. "They also have shorter wavelengths, which allow them to be used with fiber optics, which CO_2 la-

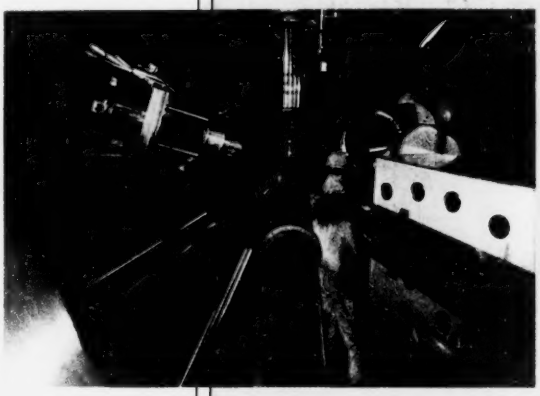




***Bright blue** fluorescence highlights an excimer laser beam (near left) used to produce low-cost tunable XUV radiation at Sandia National Laboratories.*

A solid-state blue laser (far left) was developed at Los Alamos by simultaneously pumping a Tm:YLF crystal with red and near-IR lasers.

'A big area for industrial laser research is stereolithography,' says Stephen Anderson.



A researcher checks out the laser diagnostics inside Livermore National Laboratory's main Nova fusion chamber.

Laser fusion in limbo

LASER FUSION research is on hold until the Dept. of Energy (DOE) completes a full review of U.S. fusion research policy.

After more than a year of discussions, the DOE recently assembled a Fusion Policy Advisory Committee. In September, the committee is expected to recommend how the two main fusion research programs—laser-based inertial confinement fusion (ICF) and magnetic confinement fusion—will be structured and supported.

Most program improvements are only in the proposal stage, including:

- Upgrading Livermore's 100-J Nd:glass Nova laser system to a 1-MJ high-gain system
- Upgrading the Nd:glass Omega system at Univ. of Rochester, NY, to 35 kJ
- Continuing development of the KrF excimer lasers in the Aurora ICF facility at Los Alamos (NM) National Laboratory.

"These upgrades have been endorsed by the Academy of Sciences, but the money is not in the budget. So all of them are sort of hanging at the moment," says Stephen Dean, president of Fusion Power Associates, a Gaithersburg, MD-based market-research firm.

sers cannot do," says Rofin-Sinar's Fortino. However, Nd:YAG lasers cost more and have lower power ratings than CO_2 lasers.

A few 500-W Nd:YAG lasers now are available with 1-kW versions being developed. While research will bring the current costs down, they will remain higher than CO_2 systems for some time.

Industrial firms in Japan and Europe are pursuing research in kilowatt-scale excimer lasers. They are more interested in developing high-energy lasers for industrial applications than U.S. industrial firms.

However, niche industrial applications still are being developed in the U.S., such as the development of new cutting methods for materials.

For example, Palaniappa Molian, a researcher at Iowa State Univ., Ames, is developing laser systems to cut nickel-chromium alloys, which are damaged by traditional machining. "If we use an acetylene-gas jet with a laser, we can obtain a temperature hot enough to cut and weld these materials," says Molian.

Another niche area is laser enrichment of nuclear fuels. The U.S. share of the world market for nuclear-fuel materials dropped from 100% in the mid-1970s to 50% today. To regain some of this market, scientists at Lawrence Livermore (CA) National Laboratory developed a low-cost uranium atomic-vapor isotope separation process.

The project, which uses copper and dye lasers to separate different uranium isotopes in a purification process, has been under development for several years. Performance demonstrations are scheduled for 1991. The National Academy of Sciences is studying alternate uses of this system, such as purification of industrial materials.

"A big area for industrial laser research is in stereolithography," says Stephen Anderson, market development manager for Spectra-Physics Inc., Mountain View, CA.

In stereolithography, a CAD program drives a medium-power laser, such as HeCd or argon ion, to trace the contours of a CAD-created design on uncured acrylic-polymer resin. This cures the resin in the shape of the part in minutes, compared with the hours or days that previous clay or wood methods required.

The parts made in a stereolithography system can be used as master models for mold-making processes, visualization samples for researchers, and checks for fit and function in assemblies.

Several hundred systems from such companies as 3-D Systems Inc. (Valencia, CA), Quadrax Corp. (Portsmouth, RI), and DuPont Inc. (Wilmington, DE) are already used in the U.S., while Sony (Tokyo) and Mitsubishi (Tokyo) are making similar systems in Japan.

Sony's system makes the largest parts, which can be up to 100 cm on a side. Software interfaces also are available for

Understanding the jargon

boule: A synthetically grown single crystal that is used to make solid-state lasers.
FEL: Acronym for free electron laser, a laser that uses a high energy electron beam to amplify the power in a laser pulse.
laser: Acronym for light amplification by stimulated emission of radiation.
modelock: Synchronizing a laser's harmonic modes of oscillation to create a short pulse.
pump: To use an external photon source to excite an atom from one energy state to a higher energy state.
Q-switch: Electronically build up ions in a lasing medium and then switch to a higher value just before an instability occurs, thus creating a high-power pulse.
YAG: Acronym for yttrium-aluminum-garnet, a synthetic crystal capable of lasing in the infrared. Similar acronyms include YLF (yttrium-lithium-fluoride) and GFG (gallium-fluoride-garnet).

these systems from most CAD-software companies.

A variation on this theme is selective laser sintering as shown in the accompanying figure. Developed by researchers at Univ. of Texas, Austin, and recently licensed to Austin-based DTM Corp., laser sintering uses a CAD-driven CO_2 laser to fuse powdered polymer particles into a part. "The wider range of materials that can be used with laser sintering is an advantage over other photopolymer systems," says Paul McClure, DTM's president.

Operating with lasers

"More than 90% of all ophthalmologists own or have access to lasers for performing such treatments as retinal coagulation, retinal reattachment, glaucoma alleviation, and the clearing of secondary cataracts. Ophthalmologists' love affair with the laser continues unabated," says Irving J. Arons, a senior consultant specializing in ophthalmic and medical lasers at Arthur D. Little Inc., Cambridge, MA.

Recent research in this area includes development of corneal sculpting techniques that can eliminate the need for eyeglasses or contacts in most nearsighted, farsighted, or astigmatic individuals.

In this procedure, an ArF excimer laser is used to reshape the cornea. Cellular matter is removed from the cornea by breaking molecular bonds one cell at a time with the laser. This surgery does not damage the surrounding tissue, takes less than a minute, and heals within two days.

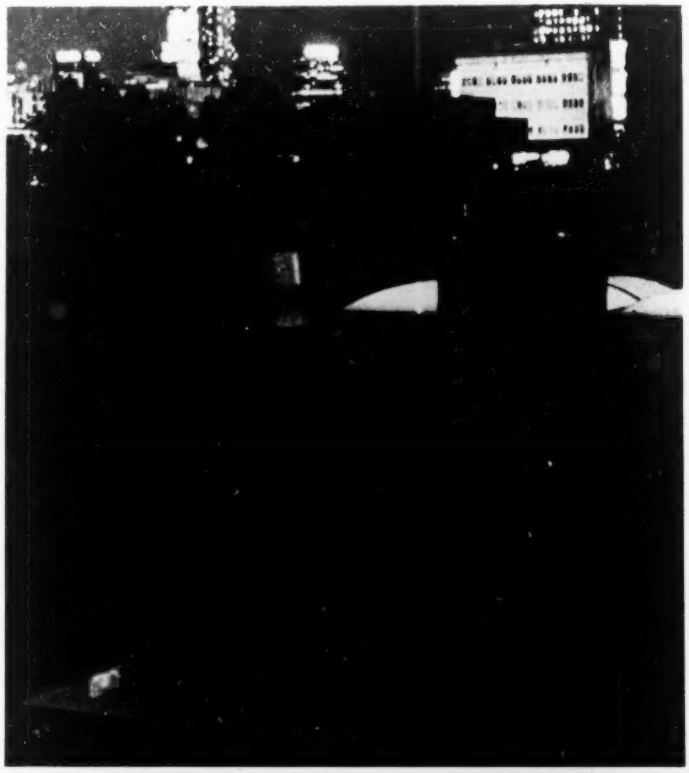
Several companies, including IBM, are battling for patent rights to this technology.

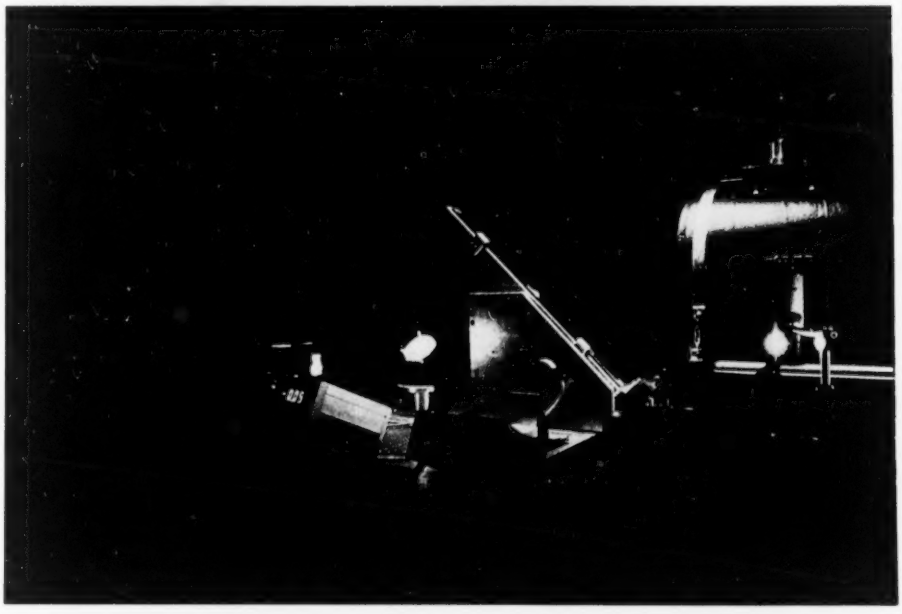
Other laser companies are developing similar processes that use diode-pumped Er:YAG, Ho:YAG, and YLF (yttrium-lithium-fluoride) lasers to vaporize subsurface corneal cells that then collapse and heal, thus changing the shape of the cornea.

Other medical applications of excimer lasers include angioplasty, arthroscopy, and dentistry. Research in laser angioplasty—the ablative removal of plaque in blocked coronary arteries—has been hindered recently by professional concerns over the effectiveness of any type of angioplasty, mechanical or laser.

In arthroscopy, CO_2, excimer, Nd:YAG, and Ho:YAG lasers are used in complementary procedures to remove both soft and dense tissues.

"However, the absorption coefficient for water at the 2,100-nm wavelength of newer





A Georgia Tech researcher (below) sends a laser beam into the air above Atlanta (left). An analysis of the beam's returned scatter shows wind velocities, air turbulence, dust, smoke, and CO_2 content.

The most significant recent event in spectroscopy is the introduction of titanium-sapphire lasers.

R&D Perspectives

Ho:YAG lasers is 20 times better than for the traditional Nd:YAG wavelength of 1,060 nm," says Ahmad Abu-Shumays, an engineering program manager for Coherent Medical Group, Palo Alto, CA. This makes the Ho:YAG more effective at cutting through cartilaginous tissue.

In dentistry, an excimer laser can be used to "drill" holes in tooth enamel, while a pulsed-Nd:YAG laser vaporizes any tooth decay.

The tunability of pulsed-alexandrite (chromium-doped chrysoberyl) lasers allows them to be used to develop photodynamic-therapy (PDT) methods to treat cancer. PDT is the in vitro killing of cancer cells by high-energy pulses of specific wavelength laser light without harming surrounding healthy tissues.

The U.S. has the lead in laser-based medical technology over slightly smaller efforts in Japan and Europe.

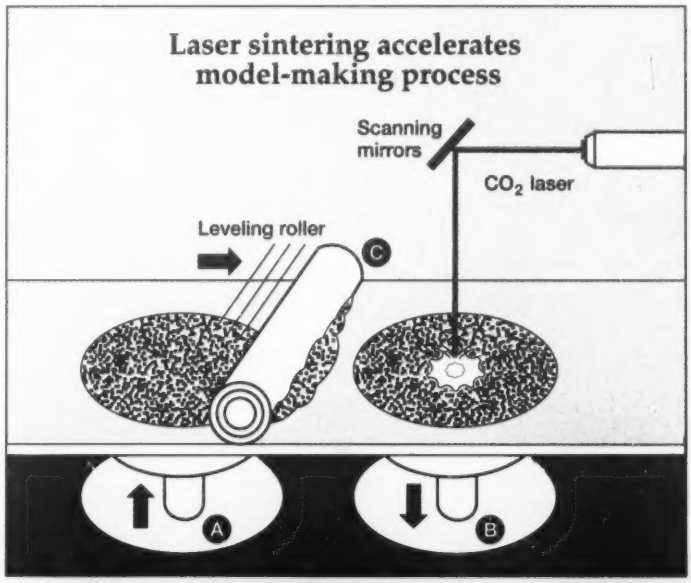
The application of lasers to analytical measurements varies from well-known laser spectroscopy and interferometry to lesser-known methods, such as dosimetry, adhesive-bond measurements, and thermal diffusivity.

Spectroscopy follows range finding and interferometry as the newest analytical application for lasers. The most recent event in laser spectroscopy has been the introduction of titanium-sapphire (Ti:sapphire) lasers that complement the performance of traditional dye lasers.

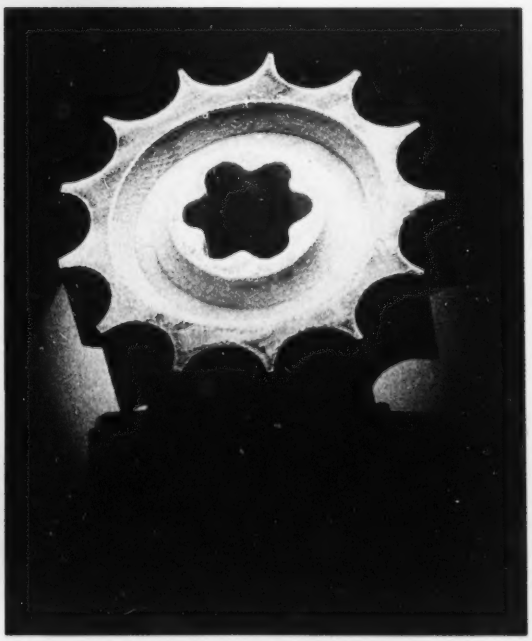
The power of Ti:sapphire lasers is significantly higher than dye lasers with fewer shortcomings, primarily the elimination of carcinogenic dyes.

New lasers are being developed for laser spectroscopy, such as the cobalt-doped MgF_2 laser developed by Peter Moulton at Massachusetts Institute of Technology's Lincoln Laboratory, Cambridge, and the chromium-doped $LiCaAlF_6$ laser at Livermore National Laboratory. The tunability of these and other solid-state lasers is the driving force in laser spectroscopy.

Combinations of existing systems also have proven to be useful for research applications.



A laser sintering system has two cylinders, one pushing powder up (A) and one lowering to receive powder (B) from a leveling roller (C). A CO_2 laser scans and fuses the powder to a desired cross section.



It took only a few hours to generate this gear design (near right) on a CAD system and use the computer output to drive a laser sintering system to make a plastic part (far right).

'Ophthalmologists' love affair with the laser continues unabated,' says Irving Arons.

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For example, researchers at Oak Ridge (TN) National Laboratory combined resonance-ion mass spectroscopy (RIS) with a laser-induced fluorescence-spectra system to design an instrument that monitors the growth of high-temperature superconductor thin films.

Combining laser systems also worked for Battelle's Pacific Northwest Laboratories, Richland, WA. At Battelle, researchers combined two dye lasers with a CO_2 laser to develop a double resonance ionization mass spectrometer (see accompanying figure). This instrument is hundreds of times more sensitive than conventional techniques in the measurement of trace elements, such as lead-210 and strontium-90.

Laser acoustics is another analytical technique being developed. At Georgia Institute of Technology, Atlanta, researchers Yves Berthelot and Jacek Jarzynski have developed a laser probe that nondestructively measures sound in submerged structures. "We're trying to understand the physics of how sound waves are radiated," says Berthelot.

Their system uses laser-Doppler interferometry methods. A beamsplitter divides a laser beam into two beams, which are fed into two fiber optic cables that transmit the beam to the experiment. There, the two laser paths are crossed at the vibration point under study. The light beams scatter off the structure, and the vibrations modulate the light. Berthelot and Jarzynski then analyze the resultant data to obtain information on the vibrations.

Researchers at Idaho National Engineering Laboratory, Idaho Falls, use similar laser acoustic methods to measure the micromechanical resonance of materials. The initial application involves testing the adhesive bond integrity of space shuttle thermal tiles (see accompanying figure).

A laser-based dosimetry—radiation detection—measurement system has been developed by researchers at National Institute of Standards & Technology, Gaithersburg, MD. The system uses a HeNe laser light source to monitor processes such as polymer curing, sterilization of medical equipment, and semiconductor hardening.

Hot optical research

Nonlinear optics, self-scanning detector arrays, and optical fibers are hot areas in electro-optics research. Nonlinear optics are used to frequency double dye and solid-state lasers for spectroscopic applications.

Spectra-Physics has developed a beta-barium borate crystal that efficiently doubles a laser frequency below 200 nm for high-energy pulsed lasers. "However, the material is hard to obtain—it comes from China—and we are [codeveloping] a similar material, lithium borate," says Sicco Westra, manager of solid-state laser systems at Spectra-Physics, Mountain View, CA.

Researchers at Epitaxx Inc., Princeton, NJ, have developed an InGaAs multiplexed linear photodiode array that performs the same function as traditional multiplexed silicon devices, but in the near-IR as opposed to the UV-visible spectrum. This detector has applications in near-IR spectroscopy, where it performs better than the conventional germanium detectors.

Researchers at AT&T Bell Laboratories, Murray Hill, NJ, have developed an erbium-doped optical amplifier fiber for use as a fiber-optic communications cable. Its 1,550-nm signal is pumped with a 1,480-nm semiconductor laser. This amplifies the optical signal 100

Will politics shoot down SDI lasers?

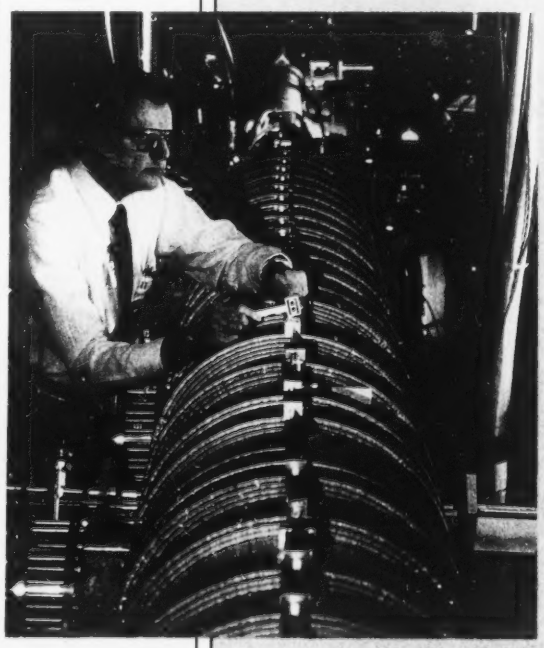
POLITICS WILL determine the future role of high-energy laser research in the SDI (Strategic Defense Initiative) program. The Bush administration's proposed FY91 budget for the directed energy weapons (DEW) category of SDI is $810 million, up from $703 million for FY90.

If SDI survives FY91 budget battles, high-energy laser programs still will have to compete against internal SDI programs, such as development of neutral particle beams and kinetic energy weapons (KEW). Most Congressional representatives favor DEW weapons, while the administration favors KEW.

Of the $810 million, the administration proposes spending $211 million for chemical laser research and $130 million for free electron laser (FEL) research.

Last fall, Boeing, Seattle, and Los Alamos (NM) National Lab won an SDI contract to develop an FEL that's expected to be the world's largest, when it's completed.

As part of DEW system research, a low-power atmospheric compensation and relay mirror experiment satellite was launched in January 1990. The satellites will be used during the next several months to develop data on long-distance optical paths of lasers and interaction of laser beams with the atmosphere.



Boeing engineer Dick Lowrey uses a magnetic probe to check the magnetic field around the company's free electron laser system.

AT&T developed a laser-pumped fiber-optic cable that amplifies optical signals 100 times.

R&D Perspectives

times at a pump power of less than 4 mW. This in-line amplifier eliminates the signal-conversion and reconversion process needed in traditional systems.

Making blue lasers

Developing a solid-state blue laser has been a goal of researchers for some time because of its potential use in communications, therapeutics, chemical analysis, and consumer electronics.

Researchers at Livermore National Laboratory and Los Alamos (NM) National Laboratory both have developed blue lasers, but with different processes.

To make his blue laser work, Livermore researcher Richard Solarz made Nd operate in a ground-state depletion mode in a Y_2SiO_5 crystal grown at AT&T Bell Labs. "The magic about this is that when the Nd lases back to the ground state, simple frequency doubling takes it to 455 nm (blue wavelength)," says Solarz.

To operate his blue laser, Los Alamos researcher Dinh Nguyen uses an "upconversion" process in which thulium ions become excited by absorbing low-energy IR photons from a semiconductor laser. The electrons jump to a high-energy level from which they emit a high-energy blue photon (see accompanying figure).

Upconversion generates the same visible light power as gas lasers, but with efficiencies almost 100 times greater than with conventional gas lasers. One potential application is in the replacement of hazardous wet chemistry techniques. "They can be used in a number of defense and R&D areas—anywhere other visible gas lasers are being used," says Allen Hartford, head of the chemical and laser sciences division at Los Alamos. **R&D**

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Laser & Electro-Optics Manufacturers Assn., 72 Mars St., San Francisco, CA 94114; 415/621-5776

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Scientific Events

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Lasers and electro-optics business highlights

U.S. laser patents drop

U.S. Dominance in laser technology has eroded during the past several years. Last year, U.S. inventors received 714 laser patents, 21 fewer than in 1987. During the same period, foreign-based researchers increased their total number of patents from 550 to 663.

The biggest holder of U.S. laser patents is the Federal government. In 1988, the Dept. of Defense received 43 laser patents, the Dept. of Energy received 24, and NASA was awarded 3 patents.

For more information: MicroPatent 800/648-6787.

U.S. laser market grows

Materials processing, R&D, and medical applications account for more than 75% of the $314 million U.S. laser market, according to a recent study by Frost & Sullivan, a New York-based market research firm. The U.S. accounts for about half the total world market in lasers.

U.S. sales are expected to reach $412 million by 1994. Ion, CO_2, and solid-state lasers are the strongest growth areas with combined U.S. sales of $195 million in 1989 and forecasted annual sales of $260 million by 1994.

Next: Corneal sculpting

More than half of the ophthalmologists in a recent survey said they would charge between $1,000 and $1,500 per eye to perform laser-based corneal sculpting, according to Arthur D. Little, a consulting firm based in Cambridge, MA.

The laser sculpting procedures use an ArF excimer laser to remove corneal material. The reshaping procedure takes less than a minute and can eliminate the need to wear glasses or contacts.

"Five years after FDA marketing approval, there will be 2 million sculpting procedures performed annually," says Irving J. Arons, a senior consultant in medical laser technologies for Arthur D. Little.

A global laser industry

Patent holders	1989	1988
U.S. government	58	70
Hitachi	34	36
Toshiba	32	26
Sharp	27	39
Mitsubishi	27	37
Hughes Aircraft	27	22
Siemens	25	27
General Electric	25	21
Spectra Physics	20	18
Minolta	20	5
Canon	20	14

Source: MicroPatent

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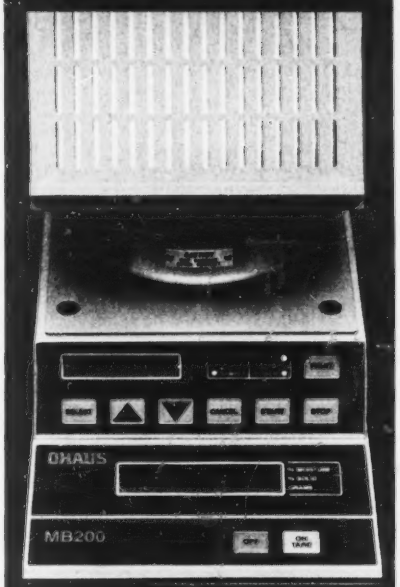

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